CORNELL AERONAUTICAL LABORATORY, INC.

Buffalo, New York

Quarterly Progress Report No. 9

SHOCK TUNNEL INVESTIGATIONS OF TURBULENT FLOW
AT HIGH MACH NUMBERS

Contract No. NSR 33-009-029
Project No. PR 10-6222

Reporting Period: 1 July through 30 September 1967

Objective

The objective of this investigation is to further develop instrumentation for shock tunnel studies of turbulent boundary layers and to obtain preliminary experimental information in the boundary layer of the hypersonic shock tunnel nozzle.

Electron Beam Density Probe

A significant increase in the beam current obtainable with the equipment to be used in the shock tunnel tests has been achieved by using a magnetic focusing coil between the open chamber and drift tube. Whereas a beam current of approximately 100 microamps had been typical of operation without the focusing coil, now beam currents of approximately 4 milliamps (40 times the previous value) are being achieved for the same filament current. This improvement in performance should increase the beam stimulated radiation relative to background radiation and relative to system noise levels. Whether the improvement is sufficient to permit recording of the density fluctuations as distinct from system noise remains for further investigation. However, efforts will be made in the shock tunnel program to record a limited number of data points with sufficient frequency range to permit a spectral analysis.

In the previous progress report the possibility had been raised that extension of the bandwidth of recorded light to include the N_2 second positive band systems might extend the linear operating range to higher densities. However, some recent experiments conducted at CAL independent of this contract have indicated that secondary electrons may play a significant role in the N_2 2P emission. Thus the ambient translational temperature of the gas may be important. Although experiments at General Electric by Boyer and Muntz (Ref.1) indicated no temperature effect between static temperatures in a flowing gas of 80°K and 210°K, the experiments planned here will record densities in turbulent boundary layers with static temperatures as high as approximately 2000°K while the calibrations of photomultiplier output versus density will be obtained at room temperature (300°K). The present intention, therefore, is to continue to use the filters admitting the 0-0 and 0-1 bands of the N_2^+ first negative system. The calibration will be extended to the pumping limits set by the requirement to maintain a low pressure in the gun chamber, with the intention of using the nonlinear portion of the calibration curve to achieve sufficiently high densities (equivalent pressures of 2 mm Hg and above).

Pitot Probe Development

The Air Force-sponsored development of a fast response, 1/8-inch, pitot pressure probe has essentially been completed with the running of a series of four evaluation runs in the shock tunnel. The probe response with the exposed (flush) diaphragm has proved to be somewhat erratic when compared with the response of probes having a cap placed over the end of the probe. With protective caps, three 1/8-inch probes tested simultaneously in the shock tunnel agreed to within one percent. The probes with unprotected diaphragms varied by 20 percent and yielded irregular trace shapes. The cap has a small orifice and a small gas volume above the diaphragm, which, in part, produces a favorable degree of viscous damping of the fluctuating pressure to which the probe is exposed. As a means of checking the gage response to transient heating, probes were exposed to flash bulbs. The probes with protective caps were found to be less sensitive to the radiant heat transfer to the probe surfaces than the flush diaphragm configuration, even when it was covered with a protective coating of rubber and foil. The flush diaphragm configuration had been viewed as the most desirable for the boundary layer tests because of its direct response to stream dynamics and because it provides as a means of avoiding the apparent acoustic resonance effects. Apparent resonance effects had been observed in an earlier test which used probes with minimum tube lengths of 3/8-inch from the probe tip to the transducer diaphragm. However, it now appears that a protective cap with a small gas cavity is desirable as a means of suppressing large amplitude fluctuations which might themselves introduce electrical non-linearities and is also desirable as a means of thermal protection for the sensitive crystal.

Shock Tunnel Boundary Layer Experiments

During this reporting period the design and construction of all the necessary special test hardware has been completed, including an instrumented nozzle extension for the contoured, Mach 8 nozzle; the light collecting system of lenses, fiber optics bundles, and photomultipliers; the pitot pressure rake for the 1/8-inch probes; and a shortened drift tube section for the end of the electron gun. At the end of the period,assembly and installation of the test hardware was in progress in preparation for the test program, presently tentatively scheduled to begin 23 October 1967.

Following a short series of runs to evaluate possible interference effects between the electron beam, wall instrumentation and pitot probes, boundary layer measurements of density and pitot pressure will be made simultaneously with wall measurements of pressure, heat transfer, and skin friction. The actual test conditions will depend on the calibration limits for the electron beam and the number of test conditions run will depend on the effort required to achieve quality data and on the funds remaining in the contract. In order of priority the tentative test conditions are listed in Table 1.

Current Status and Future Plans

A set of drawings showing the test equipment is being sent under separate cover to Mr. Ivan Beckwith, NASA Langley Research Center. During the next reporting period it is planned that shock tunnel testing and data reduction will be completed and that analysis of the experimental results will be essentially completed. As of 30 September 1967, funds expended on this contract were $118,005 toward an authorized total cost of $148,712.

Reference

1. Boyer, A.G. and Muntz, E.P. Experimental Studies of Turbulence Characteristics in the Hypersonic Wake of a Sharp Slender Cone in Fluid Physics of Hypersonic Wakes, AGARD CP No. 19 (May 1967)

Table I

TURBULENT BOUNDARY-LAYER TEST PROGRAM

CAL 4-Foot Shock Tunnel, Contoured A Nozzle, $M \cong 8$

	T_o (°K)	p_o (psia)	p_o' (psia)	p_∞ (psia)	$p_{\infty ST}$ (mmHg)	$p_{wall_{ST}}$ (mmHg)	Re_∞/ft	Remarks
a	3200	325	1.5	0.017	0.94	0.89	0.68×10^5	H_w/H_o = .07, within density probe range
b	3200	790	3.7	0.041	2.2	2.1	1.7×10^5	Higher Reynolds No.
c	2100	250	1.7	0.021	1.9	1.1	1.7×10^5	H_w/H_o = .13 at same Re as Cond. b
d	3200	200	0.9	0.011	0.58	0.55	0.42×10^5	Reynolds No. variation at H_w/H_o = .13